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INTEGRATION OF ELECTRIC VEHICLES INTO THE SMART GRID

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ABSTRACT

The need of human beings to use vehicles in transportation was met first by steam trains, then by various automobiles and other vehicles working with internal combustion engines. Today, electric vehicles are increasingly used for transportation. As in all industrial establishments and cities, it has been determined as a goal to cause less damage to the environment and to use vehicles more efficiently in transportation. Due to the increase in the use of fossil fuels and the fact that these resources are facing depletion in the coming years, developed countries have started to search for new ones. The use of electric vehicles, which emerged with these studies, is becoming widespread day by day. In addition to being environmentally friendly compared to internal combustion engines, another advantage of electric vehicles is that they can work in an integrated manner with smart grids. In this study, research is conducted on the current status of electric vehicles, their types, charge levels, advantages, difficulties in development and statistics on electric vehicle use in different countries. In addition, various concepts that emerge with the integrated use of electric vehicles with smart grids is evaluated. The advantages of including smart grids in the electricity grid infrastructure is examined. The working principles of vehicle-to-grid (V2G) systems is evaluated. The concept of "demand-side participation", which emerges with the use of vehicle-to-grid systems and contributes to the electricity supply-demand balance, is examined.

Keywords: Energy, Electric Vehicle, Vehicle-to-Grid Systems (V2G), Demand Side Management

1. INTRODUCTION

Today, there is an increase in electricity consumption due to industrialization and the increase in energy demand. With the increasing energy consumption, the reserves of fossil fuels, which are widely used conventional energy sources, are about to run out. The increase in the use of fossil fuels and the possibility of depletion of these resources in the coming years have led people to seek new resources. In this context, studies are carried out for alternative energy sources and more efficient energy consumption, taking into account the damage these energy sources cause to the environment. With the oil crises that emerged after 1973 and 1979, concerns about the use of fossil fuels have increased. With these processes, electric vehicles with an eco-friendly technology have emerged. Contrary to the damage caused by internal combustion engines to the environment, electrical vehicles have been developed as eco-friendly and it is aimed to expand their use. Despite its long history, the importance of electrical vehicles has increased in recent years. With the increasing interest in electrical vehicles, automobile manufacturers have also advanced their research studies in this direction and started mass production in various brands. In recent years, it can be said that almost every automobile manufacturer has an electrical vehicle.

2. ELECTRICAL VEHICLES

2.1. The History of Electrical Vehicle

The history of electrical vehicles, which are rapidly becoming widespread today, dates back to earlier than internal combustion engine vehicles. The first electrical vehicle model in the world was made by

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Professor Straitingh in the Netherlands in 1835. Between 1834 and 1836, an electric road vehicle was developed by Thomas Davenport in the USA. This vehicle was three-wheeled but was driven by non-rechargeable batteries. After 1859, lead-acid batteries were developed and started to be used in electrical vehicles [1]. Over the years, studies have also been carried out on increasing the range for electrical vehicles. The first hybrid vehicle was produced in 1902 by Ferdinand Porsche together with a Viennese vehicle manufacturer, Jacob Lohner, under the name "Mixte-Wagen" given in picture 1. [2,3] In this vehicle, together with the internal combustion engine, electric hub motors, placed directly in the hub of a wheel, powered the vehicle. The advantage of this design is that there is no need for an additional transmission system and the efficiency of the system is increased. Although electrical vehicles were produced and started to be used before the 1900s, their use could not become widespread due to reasons such as battery costs, short range, inability to reach high speeds compared to other vehicles, and cheap fuel in gasoline engines. For this reason, it has been a rare type of vehicle in traffic until it regained its popularity recently. As a result of the environmental policies adopted by the countries, the use of electrical vehicles has increased recently. It is known that it will be widely used in coming years.

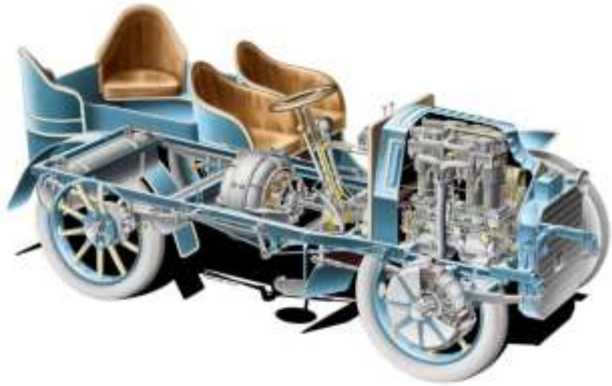

Figure 1. Mixte-Wagen Hybrid Car

2.2. Working Principle of Electrical Vehicles

Electrical vehicle is a machine that can obtain some or all of the energy of movement with the help of electric motor. The energy stored in the vehicle's batteries feeds the electric motor of the vehicle and these batteries are charged in different ways. By using this energy, the movement of the wheels is ensured. Electrical vehicles are eco-friendly and work silently. Depending on the types of electric vehicles, all or part of this movement can be provided by the battery. In addition to vehicles with fully electric, there are also types of electric vehicles that integratedly work with internal combustion engines.

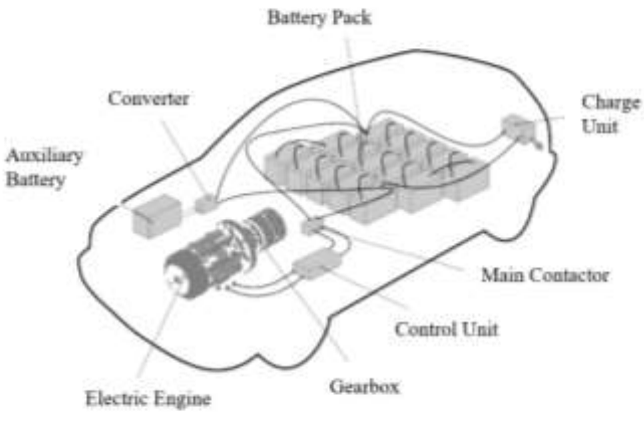

Figure 2. Parts of Electrical Vehicle

The basic parts of electric vehicles are shown in picture 2. These are the battery for energy storage, the electric motor for the propulsion system, the generator, mechanical transmission and power control systems. In electric vehicles, the propulsion system can be powered by the electric motor only or both electric and internal combustion engine. [4]

2.3. Advantages of Electric Vehicles

Electrical vehicles have many advantages.

- They are sensitive to the environment. It can be called an eco-friendly green engine.
- It has low fuel cost.
- It has low maintenance cost.
- They eliminate the need for oil, so it can also minimize the environmental damage of fossil fuels.
- It can be used as a storage system in low demand periods by being integrated into the network.
- It has low emission rates.

2.4. Challenges in the Development of Electric Vehicles

There are several obstacles to the increase in the use of electric vehicles. If these obstacles are mentioned,

- Higher purchase prices compared to the internal combustion engine.
- Not having enough charging places.
- They do not have enough range with a single charge, so they need a charging station on long journeys
- Having an uncertain second-hand market.

2.5. Types of Electrical Vehicles

As seen in Picture 3, electric vehicles can be grouped under three headings: full electrical vehicles, hybrid electrical vehicles and plug-in hybrid electrical vehicles.

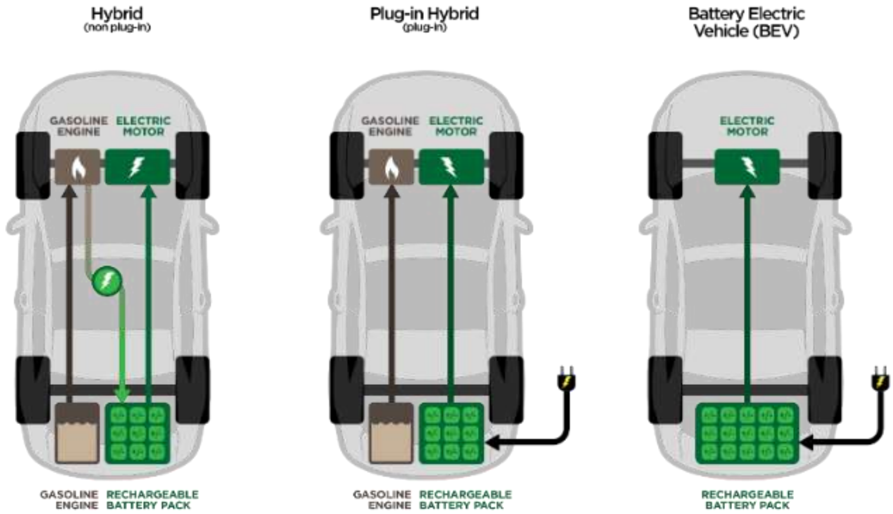

Figure 3. Types of Electrical Vehicle (https://www.nspower.ca)

2.5.1. Hybrid Electrical Vehicles

The word hybrid means "two different power supplies working together". As the name suggests, its operation is based on the principle of complementing an internal combustion engine with an electric powered engine. In the system, the electric motor is connected to the internal combustion engine in parallel or in series. The hybrid power conditioner establishes the connection between the battery and the electric motor and feeds the vehicle's power supply. The hybrid battery in the vehicle does not need to be charged with a socket. Owing to regenerative systems, vehicles convert kinetic energy into electrical energy at the moment of braking and charge the battery itself.

2.5.2. Plug-in Hybrid Electrical Vehicles

Plug-in Hybrid vehicles have an internal combustion engine and an electric motor. The difference from hybrid cars is that the vehicles have plug-in inputs. Using this type of electric motor, the battery must be charged at the electrical outlet or charging station. They can work with an internal combustion engine and a charged battery. They can work with an internal combustion engine and a charged battery. These cars have a powerful battery capacity. Therefore, it has an efficient electric motor power. These electrical vehicles attract more attention from users.

2.5.3. Fully Electric Vehicles

Fully electrical vehicles are vehicles that provide movement using only an electric motor. In order for the batteries to be charged, the electric motor in the vehicle is used as a generator. The motor produces electric and feeds the batteries with the energy. The components in these systems are important for the performance and efficiency of the electrical vehicle. Although being eco-friendly is an important advantage, the high cost of batteries in long-distance use and the long battery charging time are the most important obstacles for the widespread use of electrical vehicles.[6]

2.6. Charge Levels of Electrical Vehicles

Electrical vehicles have 3 different charge levels. These are called Level 1, Level 2 and Level 3. Electrical vehicles can be charged with AC type chargers using alternating current method or DC type chargers using direct current.

2.6.1. Level 1 Charge

This charge level is known as slow charge. It has a voltage of 120 V. It can be charged by plugging into an ordinary outlet. With this charge level, the vehicle can travel 6-8 km in a 1-hour charge. It has a full charge time of 7 to 29 hours. There is no power converter in the charging process. Due to insufficient in terms of protection, it is dangerous. Its use is banned in many countries.

2.6.2. Level 2 Charge

Level 2 charge is faster than Level 1. Level 2 is a medium fast charging type and operates at 240V-400V voltage. In the Level 2 charging system, there is a control adapter different from the Level 1. Therefore, it is a safe system according to Level 1. It can be travelled between 25-40 km with a 1-hour charge. It may take between 2-10 hours for the batteries of these vehicles to be fully charged. Level 2 charging does not include any power converter.

2.6.3. Level 3 Charge

Level 3 charging type is DC charging type that is fast. DC charging is obtained by converting from AC power. Level 3 chargers that require assembly offer charging via 480V AC or DC plugs. Using the CHAdeMO or CCS connector, which accelerates charging with a charge rate of 43 kW to 100+ kW, the charging time can be from 20 minutes to 1 hour. Both Level 2 and Level 3 chargers have connectors attached to the charging stations. (https://www.kia.com/) In this charging type, approximately 65 km can be traveled with a 10-minute charge. With this charging type, it takes approximately 30 minutes to fully charge the vehicle. In Level 3 charging type, charging elements are not mounted on the vehicle. In these charging stations, depending on the DC type, there are elements required for the charging process. In Figure 4, charging times are given for Level 1, Level 2 and Level 3 with Tesla Model S and X 100D .

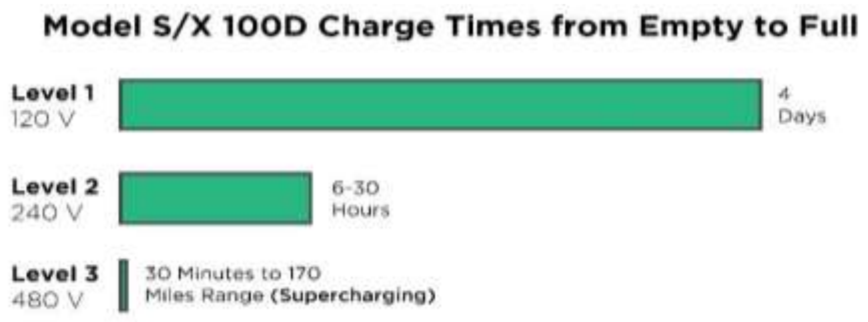

Figure 4. Charging time according to Tesla Model S/X 100D charge levels (https://www.pluglesspower.com/)

2.7. Charging Units of Electrical Vehicles

The vehicle charger is the equipment that safely performs the flow of energy to the electric vehicle. Charging units are used in different structures in different parts of the world. The most important of these differences are DC and AC charging types. The ability to charge DC and AC is related to whether the electric vehicle has an internal (on-board charging) system or not. Vehicles with DC charging system have faster charge levels than vehicles with AC charging system. Countries have set various standards for the charging of electric vehicles. Japan has adopted the CHAdeMO standard and has developed units that charge vehicles with DC. In this way, up to 62.5 kW of energy can be transferred to vehicles. The IEC 62196 standard adopted in Europe can transfer energy up to 3 phase 43.5 kW with AC charging. In America, it can charge up to 19.2kW with AC charging and SAE J1772 standard [7].

As of 2020, there are approximately 800 private and public vehicle charging stations throughout Turkey (http://www.tehad.org.tr). Looking at the installed charging stations, it is seen that IEC 61851 Mode 3 charging method and Type 2 socket are preferred for AC charging. There are combo sockets at the charging stations for vehicles and sockets with different standards. Figure 5 is an example of a charging unit with a combo socket.

Figure 5. Vehicle charging station with CHAdeMO and CCS sockets (Istanbul-Akbatı Shopping Center)

3. SMART GRIDS

Smart grids are electricity distribution networks that are basically shaped by the integration of information and communication systems. Smart grids are systems that provide a sustainable, safe and efficient energy network by providing real-time bidirectional information flow between energy production and consumption [8].

Renewable energy sources and electrical vehicles can work in an integrated manner with smart grids. It can help the widespread use of clean energy and the less and more efficient use of fossil fuels, resources are depleted over the years. Incorporating the Smart Grid into the existing power grid infrastructure provides the following benefits:

- It ensures the safe operation of the electrical network.
- It ensures bidirectional information flow in the electricity supply process.
- It enables renewable energy sources to work integrated with the grid,
- It enables not only the supply side but also the demand side to influence electricity pricing.

Table 1. Differences between conventional grids and smart grids.[9]

CONVENTIONAL GRID	SMART GRID
The customer informs call center about power cuts.	The Energy Company sees the cut, isolates it automatically and/or remotely re-powers it
The energy company does whatever it takes to meet peak demand.	The utility manages peak demand, reduces its CAPEX.
It is difficult to connect renewable/distributed energy sources to the grid.	The necessary infrastructure is in place to connect Renewable/Distributed energy sources to the grid.
MV/LV losses are considered around 10%.	MV/LV losses are reduced of 7-8%.

As seen in Table 1, smart grids have differences from conventional grids. Smart grids reduce system CAPEX, provide infrastructure for the integration of renewable and distributed grids, and reduce MV/LV (medium voltage/low voltage) losses to lower levels compared to conventional grids.

3.1. Electrical Vehicles and Smart Grids

The use of electric vehicles with smart grids will provide a significant benefit to the grid in order to ensure the supply-demand balance in the system. If electrical vehicle owners charge their vehicles during the hours when the electricity demand is low, it will prevent negative situations in the electricity grid and ensure safer and more efficient operation of the grid. Modelling of EVs in New England in the US showed that a 25% EV share in the system charged in an uncontrollably would increase peak demand by 19%, requiring significant investment in grid and generation capacities. However, spreading the load over the evening hours could cut the increase in peak demand to between 0% and 6%. Charging only at off-peak hours could avoid any increase at all in peak demand [10]. With the developments in electric vehicles and smart grids, Vehicle-to-Grid Systems (V2G), which is still under development, gains importance. These systems can also balance the increase in energy demand of electric vehicles on the grid. The Vehicle-to-Grid, also known as the V2G system, is a very important system in the transition to clean energy. These systems are basically that electric vehicles give the stored energy to the grid and re-take it from the grid. Vehicle-to-Grid system (V2G), with its storage capability, enables electric vehicles to store or discharge electricity produced from renewable energy sources. This system provides the flexibility needed to integrate multiple renewable energy sources. With 100% EV penetration in 2050 in Denmark, Germany, Norway and Sweden, if no V2G is applied, the peak of the net load curve would increase by 20% in Scandinavia and Germany (from 127 GW to 152 GW) [10]. The ability of electric vehicles to operate bidirectionally (G2V-V2G) can be of great benefit to electricity grids. The cost of vehicle charging can be reduced by operating the G2V mode during low energy demand hours. In cases where the demand is high or there are power cuts, it can be returned to the grid, both to make a profit and to help prevent situations such as load shedding by ensuring the continuity of electrical energy. It ensures the balanced operation of the grid by preventing situations such as price increases and power cuts that occur as a result of supply-demand imbalance.

3.2. Demand Side Participation in Smart Grids

With the integrated operation of electrical vehicles with smart grids, the concept of Demand-Side Participation emerges. Demand-Side Participation is a term which electricity consumers change their usual electricity consumption regimes in line with market prices or instructions given by system operators. Demand-Side Participation aims to achieve goals such as balancing electricity supply and demand at a lower level by reducing electricity system expenditures and carbon emissions, flattening the electricity load curve and changing consumer electricity demand. Demand-Side Participation encompasses demand-side technologies, incentives, actions and programs, aimed at managing and reducing electricity consumption to contribute to these goals (https://www.tskb.com.tr).

3.2.1. Demand Side Participation Working Structure

Demand participation is an increasingly important tool in developed markets. In terms of logic, it is based on a very simple purpose: " The reaction of the consumption side to the price" [11].The Demand-Side mechanism is used to maintain the supply-demand balance and is achieved by shifting the load of market players. Thanks to flexible loads, it prevents the operation of inefficient power plants and reduces energy costs. Demand Participation is the response to a stimulus that changes the electricity demand in a market. The response to this stimulus aims to establish various relationships and achieve beneficial results. These efforts include promoting grid reliability, ensuring that demand does not exceed supply, and flattening the demand curve by shifting consumption from peak hours to non-peak hours during peak demand periods.

- It allows safer operation of the grid system.
- It is ensured that consumers have an impact on electricity pricing.
- It enables renewable power plants to be integrated into the system and helps to protect the environment.
- It reduces foreign dependency on energy at the national level.
- It prevents power cuts caused by load imbalance in the system and provides a more balanced grid infrastructure.

Demand side management can be used for different purposes such as reducing peak demand, filling low demand times, strategic demand savings, strategic demand growth, load shifting and flexible load shaping. The graphics in Picture 6 show the management strategies for ensuring the supply-demand balance of energy along with the demand side management.

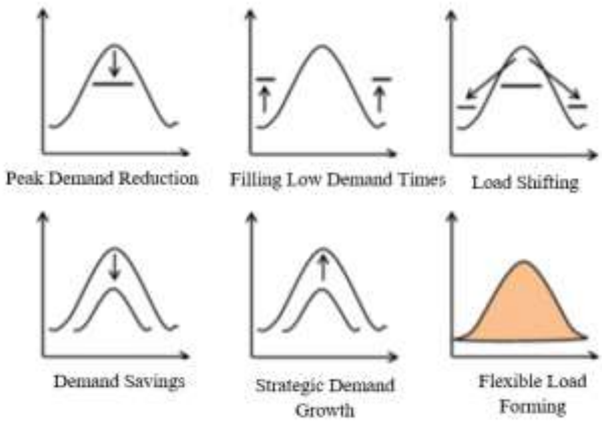

Figure 6. Demand Side Management Strategies [12]

A job that needs to be performed using energy with load shifting, which is one of the demand-side participation methods, can be performed in many ways by shifting it from the current time period to another time period. In Figure 7 below, different working situations show where the same work can be done without changing the total energy consumption.

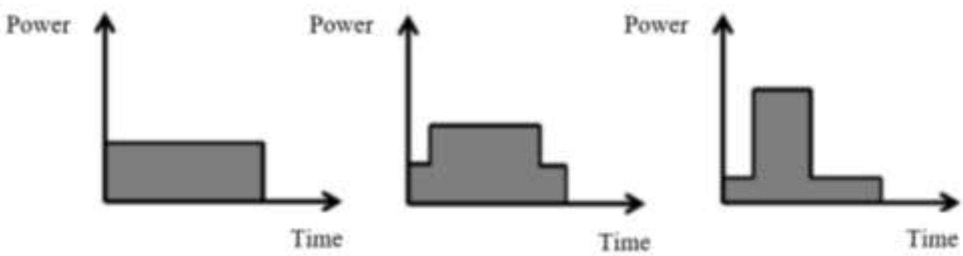

Figure 7. Different Working States of Equal Powers According to Time [12]

With the increasing use of electrical vehicles, the importance of the demand side concept is increasing. Electrical vehicles can work with the entire grid in a user-friendly way, with the creation of a smart charging system by using the vehicle's batteries. This system is the modulation of vehicle charging according to the electrical system balance and pricing movements. It includes actions such as slowing down, accelerating, stopping or delaying the charge. According to these actions, Upward or downward movements will occur in the graphs above, thus preventing negative situations such as heavy load accumulation and high pricing in the grid.

4. CONCLUSION

Due to the depletion of fossil fuels day by day, it is predicted that the use of alternative energy sources will increase and the dependence on fossil fuels will decrease. For this reason, the use of electric vehicles is increasing day by day. With these vehicles increasing day by day, it is inevitable that the number of internal combustion engine vehicles will decrease, and the electric vehicle technology will develop further. This result will require new needs and new systems to be installed. At this point, smart grids are an important component to meet these needs. Increasing energy production and consumption day by day makes it difficult to balance supply and demand. With smart grids, this balance can be achieved safely and efficiently. The energy obtained from renewable energy sources can be used efficiently in the grid. The integration of electric vehicles with smart grids enables the grid to operate dynamically and efficiently. To ensure this operation, system regulatory policies should be published and the public should be encouraged to use electric vehicles. Smart charging infrastructure should be established for smart charging services such as energy and power management systems to integrate with distributed/renewable energy sources. Standards should be set to encourage the installation of electric vehicle charging stations and to integrate them into V2G systems. In order to ensure these integrations, a pilot area should be determined and the electric vehicle charging system should be combined with the existing grid systems. Air conditioners, air conditioning systems are examples of existing systems and these systems can be integrated with the charging system. With the implementation of demand-side participation, electric vehicle owners have an important share in ensuring the supply-demand balance. For example, electric vehicle owners will integrate their vehicles into the grid. In cases where there is an increase or decrease in demand, electric vehicles will store energy or deliver the stored energy to the grid. In this way, it will protect the system from the negative effects of load shortage/excess. For people who do not have an electric vehicle, incentives can be provided for the establishment of vehicle charging stations. By making necessary agreements with charging station companies, it can own a charging station in public places and earn additional income. With the demand side participation, the grid works dynamically, electric vehicle owners have an important role in ensuring the supply-demand balance. As a result of the increase in the use of electric vehicles in the world, demand-side participation becomes one of the optimum solutions to ensure the balance and efficiency in the grid.

CONFLICT OF INTEREST

There are no conflicts of interest regarding the publication of this article.

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